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COST BENEFIT COMPARISON OF THE TACTICAL COMBAT OPERATIONS, ARMORED VEHICLE VARIANT AND THE MULTI-APPLICATION COMMAND AND CONTROL KIT

by

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ABSTRACT

In the near future our combat units will evolve into an integrated military force through the utilization of weapon systems that employ digital electronics to acquire, exchange, and employ timely digital information throughout the battlespace. This thesis justifies the need for an on-board digital tactical data system for Marine Corps armored vehicles with the presentation of potential digitization benefits and simulation analysis results. Unique operational requirements for a vehicular combat information system are presented with specific functional and physical descriptions and life cycle cost estimates for two candidate systems. These systems are analyzed and compared using a fixed effectiveness approach to cost benefit analysis. Conclusions and recommendations for the Marine Corps' evolution to battalion and below battlefield digitization are included.

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I. INTRODUCTION

A. OVERVIEW

The United States Marine Corps is currently developing the strategy and evaluating the technology to implement battlefield digitization concepts. As defined by the Digitization of the Battlefield (DotB) Working Group established by the Director, Command, Control, Computers, Intelligence, and Interoperability (C4I2), "Digitization of the Battlefield is the application of Information Technologies to acquire, exchange, and employ timely digital information throughout the battlespace." This definition, driven by continuing information technology advances, forms the basis for specific operational requirements generation and system development.

Funding the Marine Corps' digitization effort is the Office of the Secretary of Defense (OSD) with Program Budget Decision 105 (PBD-105). "PBD-105 provided $411 million to the U. S. Army research, development, test and evaluation (RDT&E) authorization during FY 95-99 for equipping Army and Marine Corps armored vehicles with a digital communications overlay system to include: a situational display, Global Positioning System (GPS) compatibility, and message interface using SINCGARS radios." (DotB, 1994) $40 million of this amount was redistributed to Procurement Marine corps (PMC) funds to ensure that a focus would be maintained on the procurement of a system for Marine Corps vehicles.

As the Marine Corps forges ahead in the effort to digitize battalion and below units, a number of candidate tactical data systems (TDS) which possess comparable attributes will present themselves. The presence of more than one technology source, coupled with the reality of a limited budget, necessitates a careful analysis of system alternatives. A common and very useful analytical method is

to perform a cost and operational effectiveness analysis on candidate systems to determine which is the more appealing from an economic and performance enhancing viewpoint.

This thesis will analyze and compare two tactical data systems: 1) the Tactical Combat Operations, Armored Vehicle Variant (TCO Armor) and 2) the Multi-Application Command and Control Kit (MACCK).

The TCO Armor is being developed by a team at Naval Command, Control and Ocean Surveillance Center In-Service Engineering (NISE) East Coast division in conjunction with the Marine Corps' TCO program office. It is intended to be a fully compatible derivative of the TCO, the Marine Corps' automated command and control system. The TCO Armor will use commercial off-the-shelf (COTS) hardware, coupled with a modified version of TCO software tailored for units below the battalion level. Individual systems will act as part of a fully distributed and integrated digital combat information system.

The MACCK is a command, control, communication, and intelligence (C3I) system "which prepares, collects, organizes, displays and disseminates pertinent battlefield C3I information to task force assets at the battalion echelon and below." (SA-MACCK-00001) Developed and produced by General Dynamics Land Systems Inc., the MACCK is an applique system built to militarized standards. It is being developed to fill the immediate Army digitization needs of the Brigade '96 program. This is an ambitious endeavor in which the Army intends to digitize a brigade size unit by 1996. Although targeted for compatibility with existing Army systems, the MACCK is a viable option for a system to fulfill Marine Corps digitization goals.

B. OBJECTIVES OF RESEARCH

The objectives of this study are to: 1) evaluate the need for an on-board digital tactical data system for Marine Corps armored vehicles and 2) identify which of the two candidate systems analyzed in this thesis can meet this need in the more cost-effective manner.

C. RESEARCH QUESTIONS

1. Primary Research Question

Which, the TCO or the MACCK, is the most cost-effective system to procure for use on Marine Corps armored vehicles?

2. Subsidiary Research Questions

a. What are the benefits of battlefield digitization at the battalion and below level?

b. What are the core requirements for an on-board digital tactical data system?

c. What are the functional capabilities of the TCO and the MACCK?

d. What is the life-cycle cost estimate for the TCO and the MACCK?

D. RESEARCH METHODOLOGY

The analysis and presentation of current literature will be the means by which to justify the need for the procurement by the Marine Corps of a digital tactical data system for its armored vehicles. The fixed-effectiveness approach to cost/benefit analysis will be the methodology employed to meet the research objective of determining the most cost-effective system to meet this need. This approach identifies fixed performance parameters that each system is measured against. Utilizing life-cycle cost estimates as a measure of economic cost, the system with the lowest cost which most closely meets all performance parameters is determined to be the more cost-effective system.

E. SCOPE OF THESIS

The thrust of this study is two-fold. First, it intends to justify the need for the digitization of echelons below battalion in the Marine Corps. Next, it intends to provide the information and framework on which a decision maker can make an intelligent assessment of the two candidate systems.

F. ORGANIZATION

Chapter II identifies the benefits of digitized command and control and provides simulation data to justify the Marine Corps' pursuance of this concept. Chapter III discusses cost/benefit comparison techniques and emphasizes their importance in the weapon system procurement decision making process. Chapter IV provides the tactical data system core requirements which each system will be measured against. Chapter V provides a detailed physical and functional description of each system while Chapter VI presents their life cycle cost estimates. Chapter VII will conclude the thesis by discussing how well each system meets the pre-defined requirements while taking into account their respective life cycle cost estimates. Further, it will propose recommendations for the future direction of the Marine Corps Digitization of the Battlefield program.

II. BATTLEFIELD DIGITIZATION

A. BENEFITS

Four years ago, during Operation Desert Storm, many information opportunities made available by advances in digital technology were yet to be seized upon. Battalion and below level commanders depended almost entirely upon voice and visual communications to control their units and maintain situational awareness on the battlefield. In the near future our combat units will evolve into an integrated digital military force through the utilization of weapon systems that employ digital electronics and have the capability for rapid automated digital information exchange. Information is the basic ingredient that bonds and focuses effort at all levels, and its importance cannot be overstated (FMFM 3, 1993). Marine Corps armor units must capitalize on existing information opportunities by utilizing performance enhancing digital command and control (C2) technology. The benefits that can be realized from the adoption of a battalion and below level digital command and control system include:

- Enhanced battlefield integration/synchronization;
- A more rapid and accurate dissemination of intelligence;
- An increased ability to command and control on the move;
- A greater degree of situational awareness and friendly force identification capability.

Together, these potential benefits represent our grasping of existing battlefield information opportunities and provide the armor force a revolutionary increase in warfighting capability.

Effective battlefield integration and synchronization is achieved when commanders are able to accurately and timely

maneuver their forces in such a manner as to gain a decided advantage over the enemy. This maneuver of ground forces must be coordinated with the potentially devastating effects of supporting arms. Indirect fires and air support must be effectively integrated and synchronized with direct fire assets to bring an overwhelming degree of firepower on the enemy. This integration and synchronization can be achieved through battlefield digitization. Digitizing the battlefield gives forces the ability to rapidly share information across functional areas. The design of communication systems for the exclusive use by a single organization or for a specific function or mission unnecessarily isolates that system and its users. It becomes a burden on the battlefield when its lack of connectivity hinders fluid operations. The system isolation or "stovepipe" effect which results from communication systems supporting a single specific mission, function, or organization would disappear with the introduction of a fully integrated digital network. The ability to send more information faster and with a greater degree of accuracy allows commanders to direct their maneuver forces and control their supporting arms assets in a more efficient manner.

A more rapid and accurate dissemination of intelligence up and down the chain of command is a further benefit of battlefield digitization. By the end of the decade, the Army expects to have an airborne and ground-based signals intelligence/electronic warfare system capable of rapidly disseminating near-real-time intelligence with targeting accuracy to users at every level of command (Ross, 1994). The system will have the capability to collect and fuse intelligence from a variety of sensors, process the data, and send it to the organization that needs it. This sensor-to-shooter information flow will reduce the "fog of war", thereby increasing combat effectiveness.

Because future battlefields will be characterized by faster tempo, requiring even faster reactions from units, the ability to command and control on the move is essential. Effective command and control cannot be achieved without the efficient flow of information up and down the chain of command. A commander on the battlefield makes decisions based upon both direct personal observations and indirect observations made from the collection of information from various sources. After making his initial observations he orients himself to the situation, makes a decision, and subsequently acts on the decision. This decision cycle takes time, which on the battlefield is a precious commodity. Those commanders who can minimize the time it takes to execute this decision cycle give themselves a decided advantage in high-tempo combat operations. An integrated digital battle command system can offer commanders data burst communications combined with video displays, automatic position location, and far target designation capabilities. Information that a commander needs to base his observations on can be transmitted faster, with a higher degree of accuracy, and in formats conducive to easy understanding. Timely intelligence and the greater degree of situational awareness that a digital system can provide will allow commanders to increase the speed in which they execute their decision cycles. In addition, an integrated digital communication system will allow the commander to disseminate his orders more quickly and efficiently, further speeding force execution times. The goal is to never have to react to the actions of the enemy, but to have him always reacting to you. Digitization will allow the accomplishment of this goal and will contribute greatly to the tank battalion's primary mission of providing overwhelming combat power to the Marine Division.

Recent friendly fire incidents (e.g., the highly publicized occurrences during Operation Desert Storm)

emphasize the importance of situational awareness and friendly force identification. Maneuver warfare demands that the C2 support system create a common situational awareness throughout the battlespace by rapidly sharing information among the commander, his staff, key decisionmakers, and supporting forces (FMFM 3, 1993). Navigation aids such as the Global Positioning System (GPS) and the Enhanced Position Location Reporting System (EPLRS), when included in an integrated and fully distributed digital network, allow commanders to know exactly where their forces are on the battlefield. Digital technology gives commanders the ability to see a picture of the battlefield. In addition to the automatic friendly position updates sent through digital links, the commander has access to every reported enemy position as well. Whether collected through sensors and disseminated down, or seen by subordinate units and reported up, the commander has access to a near real time battlefield picture. This better awareness of friendly and enemy forces decreases confusion, improves decisions by leaders, increases the tempo of operations, and reduces the potential for fratricide.

B. CONCEPT VALIDATION THROUGH SIMULATION ANALYSIS

Simulation provides military decision-makers a very cost-effective method to evaluate new system concepts before actual system hardware is fielded. By simulating and testing the capabilities of a digital combat information system, possible system design faults and overlooked functional requirements can be identified prior to the system's fielding. Large-scale modifications and costly corrective reworks can thus be avoided. The primary focus of simulation analysis of battalion and below command and control systems has been the Inter-Vehicular Information System (IVIS). The IVIS is a computer-based distributed information management system that

is designed to enhance command, control, and communication (C3) abilities at lower echelon levels. This description compares favorably with the TCO Armor and MACCK analyzed in this thesis. The following discussion will illustrate to what extent a digital command and control system can enhance warfighting capabilities at the battalion and below level. A simulation-based assessment of IVIS capabilities performed by the Army's advanced experimental test bed, Simulation Network-Developmental (SIMNET-D), and a Combat Synchronization Analysis performed by the U.S. Army Armor Center on JANUS, a combat simulation system, will be presented.

1. SIMNET-D

The Army's SIMNET-D test bed interactively links a variety of combined arms simulators, including M1 tanks, Bradley Fighting Vehicles, FAADS, and A-10 and Apache aircraft, along with microcomputers representing tactical, administrative, and logistical combat service support elements. The vehicle simulators model real world system behavior to a degree where users can perceive them as acceptably realistic. Individual simulators have the ability to model realistic battlefield conditions, equipment status, and weapon system performance, and are linked and updated across an Ethernet. (DuBois, et al., 1991)

SIMNET-D was used to determine the performance effects on crew and platoon size units of a prototype IVIS system in an M1 tank simulator. IVIS equipped crew and platoon performance was compared to the performance of crews and platoons without IVIS. In the control condition (no IVIS), crews and platoons were required to plan and execute a C3 exercise and combat missions using conventional C3 tools. Radio network communications, the field of view from the tank's vision blocks and sights, the azimuth indicator (for direction), and a paper map with a mission graphic overlay were used by the control group. Crews and platoons in the IVIS experimental

group were, in addition to conventional C3 tools, equipped with IVIS. Features of IVIS which were modeled for the simulation included a terrain map display with own-tank and friendly tank position icons, location and heading information indicated digitally in a separate window and on the map display, a touch sensitive display with various operational functions, and a digital communications network separate from the tank's radio system. (These features are present in or are under development for the TCO Armor and the MACCK.)

The initial hypothesis was that IVIS equipped crews and platoons would perform better across a variety of objective criterion measures than would non-IVIS crews and platoons. This hypothesis proved true. Crews with IVIS required less than half the time of non-IVIS crews to plan and execute the C3 exercise. IVIS crews sent more timely, complete, and accurate own-location and battlefield reports, and successfully executed more exercise change of mission, obstacle bypass, battle position, and call-for-fire tasks. Platoons with IVIS successfully completed the offensive and defensive combat missions more frequently, completed more mission segments, successfully executed more fragmentary orders, and sent more accurate own-location and battlefield reports than did platoons without IVIS. (DuBois, et al., 1991)

This simulation strongly suggests that crew and platoon combat performance will be significantly enhanced by the presence of a digital command and control system. While the relationship between crew and platoon performance in SIMNET-D and in the real world have yet to be fully validated, the unfailing superior performance of IVIS units in SIMNET-D should be used as a strong indicator of the merits of a digital combat information system.

2. Combat Synchronization Model

The Combat Synchronization Model was developed to focus on the contributions of digitized information systems to the overall effectiveness of the brigade and below combat unit. This model simulates the information network within brigade and below tactical combat units. By entering data concerning frequency, transmission time, and processing time of tactical information, the time required for units to react to battlefield situations is determined. Like-data of digitized and non-digitized units can be collected and fed into the model to develop useful comparisons between digitized and non-digitized units. The resultant time differences can then be incorporated into a combat simulation system (JANUS), where the performance of digitized and non-digitized units can be compared in various simulated scenarios. This process allows the identification of quantifiable combat effectiveness performance measures by which to compare different command and control systems.

The study objectives of this Combat Synchronization Analysis were:

- Study the time element of current data on information flow in tactical units.
- Use available small unit data (collected largely from the previously described simulation-based assessment) to determine larger unit decision cycles.
- Develop a method for utilizing reaction times in current combat simulations to evaluate digital battle command, and develop insights by examining combat payoffs. (Combat Synchronization Analysis)

In order to achieve these objectives the Armor Center used data developed in the previously described assessment to input into a network model which replicated the communication paths within company, battalion, and brigade level units. Total delay times for the flow of information and orders were

determined and imposed on units within JANUS. JANUS combat simulations were then run for digitized and non-digitized units. The four different scenarios that were gamed for the digitized and non-digitized units were:

- Southwest Asia Meeting Engagement
- Europe Flank Guard
- Northeast Asia Hasty Attack
- Bosnia Quick Reaction Force

Distinct methods of effectiveness/performance were extracted from each scenario and served as the basis for comparison of the digitized and non-digitized units. The primary measures of performance were:

- Decision cycle times (time for critical information to reach the correct destination, combined with the time required for appropriate action to be taken).
- Time to bring supporting weapons to bear.
- Mission execution time.
- Weapons utilization rates (how many systems participated in the battle over time).
- Volume of fires (direct and indirect - over time).
- Enemy and friendly losses over time.
- Contribution of each friendly weapon system to total enemy kills. (US Army Armor Center)

Across all scenarios the digitized force proved superior to the non-digitized as evaluated by the above effectiveness/performance measures. In reviewing the simulation output several general trends which reflected the benefit of digital command and control systems over voice command and control systems became apparent. These trends include:

- Digital battle command saves time in moving information within and between units. The advantage in time increases for larger units and for complicated procedures.

- Units react more swiftly to battlefield events with digital battle command.

- Radio net utilization drops slightly when using digital battle command, yet much more information is passed.

- Leaders (especially at higher level staffs) experience dramatic increases in the amount of information requiring processing.

- Information sent using digital systems is more current and accurate than voice delivered information. (US Army Armor Center)

These trends illustrate the benefits waiting to be reaped by the adoption of a distributed and fully integrated digital command and control system. While simulation has, at low cost, revealed the potential of battlefield digitization, only the testing and fielding of actual systems will prove the worthiness of digital command and control. However, in conjunction with system testing and before the fielding phase of the acquisition process, a detailed economic analysis of candidate digitization systems must be completed to identify those systems which can offer the desired benefits at an affordable cost.

> Improving all aspects of C2 is the key to fighting smarter. Having belatedly come to recognize this fact, we can't afford to ignore it just because defense budgets shrink. Improved C2 will continue to be the basis for doing more with less. (Coakley, 1992)

III. OVERVIEW OF COST/BENEFIT ANALYSIS

A. INTRODUCTION

One of the greatest problems facing military decision makers is how to achieve the greatest amount of combat effectiveness at a low cost. The following is a brief summary of how military leaders tackle this difficult problem.

The first step is to assess the global threat and define a strategy to meet it. Leaders at the Department of Defense (DoD) and Joint Chiefs of Staff (JCS) develop the Defense Planning Guidance (DPG), which provides the services the force and fiscal guidance necessary to construct their programs. It gives the services a fiscal constraint in the form of total obligational authority with which to base the development of their Program Objective Memoranda (POM).

The POM is a six-year planning document submitted by the service secretaries to the Secretary of Defense. It contains recommendations for the detailed application of service resources. As part of a continual review of the information on proposed uses of service resources, the services conduct an assessment of risks and an evaluation of the military advantages and disadvantages of each alternative (Practical Comptrollership, 1994). Included in this review are estimates of alternative program costs and benefits.

Fierce competition among proposed programs for scarce fiscal resources requires program sponsors to defend their programs with relevant, detailed, and accurate data. A Program Strategy Board is tasked with the responsibility of final program approval. This board is faced with numerous alternatives from which to choose the most cost effective mix of programs to meet the service strategy. A cost/benefit analysis is one process by which the cost and benefits of alternative weapon systems can be assessed and compared. This analysis can provide both quantified and subjective

information to support a rational decision of which candidate weapon systems to procure.

B. WEAPON SYSTEM COST/BENEFIT ANALYSIS

1. Techniques

There are two basic approaches for making comparisons in cost/benefit analysis: (1) the fixed budget approach and (2) the fixed effectiveness approach. (Fisher, 1970)

a. Fixed Budget Approach

Using the fixed budget approach an analyst compares the likely levels of effectiveness to be attained by each alternative given a fixed budget. In other words, he determines the "best" system that can be purchased with limited available funding. In the case where combat information systems are being compared, the analyst must concern himself with both the quality of the individual system and the number of total systems required to meet mission needs. The level of combat effectiveness which can be achieved by the implementation of a combat information system is dependent upon the degree of its integration and distribution within the battlefield communication network. Therefore, the system's effectiveness is heavily dependent upon the number of systems that can be afforded. If 2000 units of a system are required to fulfill organizational needs, then the job of the cost/benefit analyst is to find the system that will provide the greatest amount of benefit at a 2000 unit procurement level and within the available budget.

b. Fixed Effectiveness Approach

In the fixed effectiveness approach for weapon system alternative comparison, the analyst attempts to determine the alternative which can achieve a specified level of effectiveness at the lowest economic cost (Fisher, 1970). The goal of achieving a desired level of effectiveness can be viewed in two different ways.

The first is to meet a quantitative performance measure, such as a fixed degree of destructive capability. When making comparisons between alternatives in this manner an effectiveness analysis is needed to determine the quantity of each alternative required to meet the desired level of effectiveness. Once this task is accomplished, the costs of each alternative are determined and compared. The alternative with the lowest economic cost is chosen to meet the goal.

The second is to meet an organizational requirement for a fixed number of systems to be fielded. In this case the required quantity of each alternative is fixed. The effectiveness analysis concentrates on unit performance parameters vice aggregate performance capability. The goal is to acquire a batch of systems that meet predefined performance parameters at the lowest cost possible.

2. Measurement of Cost

"No decisionmaker can sensibly claim to be comparing the cost and benefits of his decisions unless he has a clear and defensible notion about the meaning of 'cost'." (Fisher, 1970) In its most basic sense, a cost is a benefit lost. The cost of pursuing one option is the benefit foregone from not pursuing another. The military capability that is sacrificed when resources are used for one project instead of another is the cost of that project. This relatively abstract concept is brought to earth when costs are estimated and measured in concrete terms.

a. Life Cycle Cost Estimation

Because the objective of the cost/benefit analysis under discussion is to assist the decision maker in making choices among <u>future</u> weapon system alternatives, the cost of the candidate systems must be estimated. A generally accepted measure of cost is the dollar. As such, an estimate of the dollar expenditures associated with the procurement of a weapon system is commonly used as an estimate of that system's

cost. The life cycle cost estimate (LCCE) is the most complete predictive measure of a weapon system's future cost. It is an estimate of the total cost to the government to acquire and own a system. This includes the cost of research and development, procurement, and operation and support (Fitzgerald, 1990). This thesis will utilize the LCCE of each candidate system as the measure of its cost. There exist five primary cost estimating methodologies: industrial engineering; specific analogy; estimating relationships; extrapolation; and expert opinion.

(1) Industrial Engineering Method. Also referred to as the cost accounting method, this bottom-up approach details each task associated with the completion of a project with a comprehensive work breakdown structure. "Estimating by industrial engineering procedures can be broadly defined as an examination of separate segments of work at a level of detail and a synthesis of the many detailed estimates into a total." (Cost Estimating Reference Book, 1991) The cost estimation of each specific task is then conducted, with the aggregation of each estimate forming the program cost estimate. Because of the level of detail involved, a huge amount of personnel and material data is required to make an accurate industrial engineering cost estimate. Hence, the cost in fiscal terms and in time is often considered unduly prohibitive.

(2) Specific Analogy Method. The specific analogy method can be used when the physical attributes of a proposed system are similar to those of an existing system. When this is the case, it can be assumed that similarities in cost will also exist. If an existing tank weighing 60 tons which can achieve a speed of 40 miles per hour required a production cost of X, then a proposed armored vehicle with an estimated weight of 55 tons and speed of 45 miles per hour should have a similar cost.

Analogy is used by many private firms which have detailed information on only their own products. This is an appropriate method when the historical data required for statistical estimating or the detailed data required for industrial estimation is not available or is too costly to obtain. Further, the specific analogy method could be used to validate other cost estimating approaches.

The major downside of cost estimation by analogy is that it is essentially judgmental in nature. In order to achieve accuracy with any degree of regularity the estimator must possess a significant amount of experience and expertise. The benefit of a low cost of estimation must be weighed with the potentially devastating cost of a very inaccurate estimate.

(3) Estimating Relationships. Parametric cost estimating techniques utilize output characteristics such as weight, speed, or power to predict costs. While the industrial engineering approach depends on a detailed analysis of the inputs to a system, the estimating relationship method develops, through the use of historical data, a cost estimating relationship (CER). The CER is developed by statistically fitting a line or function to a set of related historical data (e.g., cost vs. weight, cost vs. speed). A projection of the cost of a future system is then calculated by substituting its weight (or the appropriate parameter) in the equation (Cost Estimating Reference Book, 1991).

Parametric estimating methods are particularly useful during the early phases of a weapon system's development. During this early period program developers define the mission and performance parameters that the system must achieve. The analyst can, in a very cost effective manner, develop modified estimates based on historical data to match inevitable changes in system performance requirements. This sensitivity analysis information provides the program

sponsor valuable ammunition with which to defend his program.

Some key drawbacks to the parametric approach can limit its effectiveness as an estimating tool. The development of worthwhile estimates depends on the availability of an extensive database of historical system performance information. Statistical methods tell us that as the population of relevant data points grows larger, so does the probability of achieving a more accurate estimate. However, this avenue of reasoning assumes that the relationships existing between explanatory and dependent variables in the sample will continue for the system being evaluated. This may not be the case when advances in technology push future programs further from previously established and accepted performance envelopes.

(4) Extrapolation Method. The extrapolation method is an extension of the analogy method where estimates are extrapolated from the actual cost data of a prior system. This method is useful when the system under investigation is a modification of an existing system. Because the modification will share many of the same characteristics of its parent system, the cost data can be readily extrapolated and used for the cost estimation of the modified program. This method is especially useful and inexpensive to developers who embark upon modification programs of their own systems.

(5) Expert Opinion. A cost estimation derived from expert opinion, while usually influenced by another approach, is highly subjective in nature. It is nothing more than an opinion generated by an individual expert in the field or a group of experts. The fact that separate estimates developed by different experts of equal competence can vary greatly makes this a suspect technique. Although it is the least expensive cost estimation technique, it is probably the most untrustworthy. While the prudent program manager should not totally disregard the opinion of an expert, he should

strive to validate it with a more formal approach.

b. *Time*

Time is money. The relevance of this often-used phrase is made clear when the issue of time is dealt with in a dynamic systems analysis. The LCCE of a weapon system considers the relevant stream of costs to be incurred by the development, procurement, and operation of the system over time. For the same reasons that a dollar in hand today is worth more than a dollar available a year from now, resources which are spent on weapons programs in the present are worth more than those spent in the future. This is the concept behind the procedure of discounting. Before dollars which are spent or received in different periods can be meaningfully added together, future dollars must be discounted, because they are worth less than current dollars (Fisher, 1970). While the actual procedure of discounting is simple, the selection of an appropriate discount rate is often difficult. For this reason the concept of discounting is often ignored, to be replaced by the related but different technique of dollar escalation.

Cost estimates are sometimes presented in specific fiscal year terms. The use of inflation indices allows the analyst to compensate for the decreasing value of the dollar. Future costs, while presented in constant year terms, reflect a higher level of spending for the same resources. In other words, a widget that costs $1.00 in 1994 may cost $1.10 in 1995 if the inflation index used is 10% per year.

3. Measurement of Benefits

Typically, benefits are divided into the categories of tangible and intangible. The accurate evaluation of these very different types of benefits assists the decision maker in choosing between alternatives.

a. *Tangible Benefits*

Tangible benefits are those which can easily be measured in dollar terms. An example of a potential tangible benefit resulting from the adoption of a new weapon system is manpower cost reductions. If the new weapon system allows for a decrease in operating or support personnel, the manpower cost savings could be easily calculated. If fewer new systems are required to take the place of existing systems there may exist an easily determined cost savings in the form of less required support materials or a smaller amount of storage space. These are straightforward and plainly defensible benefits to weapon system acquisition programs. However, these concrete benefits are sometimes hard to find. This is the case with the C2 systems analyzed in this thesis.

b. *Intangible Benefits*

Intangible benefits are those which are exceedingly difficult or impossible to translate into a monetary value. This describes the benefits of digital command and control discussed in the preceding chapter. An increased ability to command and control on the move or a greater degree of situational awareness are benefits to which a monetary value can not be attached. Should they then be ignored in a cost/benefit analysis? Of course not. These benefits have been given an implicit value by the fact that the effort to acquire a digital command and control capability at the battalion and below level has been initiated. This implies that DOD officials value these benefits more than the potential benefits which could be realized from another program using the same funding. Additionally, while the benefits from digital C2 cannot be valued in a monetary sense, they can be quantified in a meaningful way. This was accomplished through the simulation analysis discussed in the previous chapter. This analysis has validated the recognized appreciation for digitized C2 benefits. The question remains

as to which proposed system will make these potential benefits a reality.

c. Benefits and Alternative Comparison

When cost/benefit analysis is utilized to aid a decision maker in choosing between alternatives, three distinct component elements of the alternatives must be considered: the common component; the specified differences and; the remaining, unspecified differences (Fisher, 1970). When analyzing candidate command and control systems, the common component is the group of defined benefits provided by a generic C2 system meeting predefined performance requirements. Specified differences are non-existent in this case. Both systems must meet the same performance and organizational requirements. They each must be able to perform the same task at some minimum level of efficiency. Therefore, it is the unspecified differences in the systems which must be evaluated. The differences to be focused on in this analysis are cost and those areas where performance levels exceed or do not meet the minimum requirements.

IV. TACTICAL DATA SYSTEM CORE REQUIREMENTS

The purpose of a tactical data system (TDS) is to improve the quality and flow of battlefield information so that commanders at all levels can make and communicate informed decisions consistently faster than the enemy. This allows friendly forces to maintain a proactive posture, keeping the enemy off-balance with a tempo of operations that he cannot match.

The TDS will consist of software, hardware, and system integration to enable combat and combat support forces to exchange information and interact effectively on the battlefield. To achieve its purpose, the TDS must provide functionality in four primary areas.

- Situational Awareness
- Communication Management
- Execution of Command and Control
- Combat Support and Combat Service Support

The following is a discussion of system performance applications which support each functional area. I will discuss required and desired applications. Additionally, I will discuss requirements that fall outside of the primary functional areas but which are necessary for the successful operation of the TDS.

The reference materials I draw upon to define these requirements include: a 22 April '94 report from the Digitization of the Battlefield Working Group, established by the Director, C4I2, Marine Corps Systems Command; Attachment A (Applique Functional Requirements) to the U.S. Army's request for proposal for Brigade 96; and the Operational Requirements Document for Force XXI Battle Command - Brigade and Below (FBCB2), generated by the U.S. Army's Training and

Doctrine Command.

A. SITUATIONAL AWARENESS

The concept of situational awareness is defined as "...the accurate, near real-time, situational data and enhanced graphic/visual presentations, to provide "real-time" awareness of the changing situation." (RFP, 1994) In order for the TDS to provide this common picture of the battlefield to all users, it must possess the following capabilities.

1. Position/Navigation (POS/NAV)

The TDS must be capable of identifying, displaying, and communicating the platform physical location to an eight-digit grid coordinate accuracy level. The platform's position must be displayed on an accurately depicted digital map using standard military symbology. Further, the capability to display the location of every other platform on the communication network carrying a compatible TDS is required.

On query, the system must be able to display the icon of subordinate and adjacent units on their calculated center of mass location. It shall also display the icon of a higher headquarters unit on its location when queried. Friendly unit icon location and status information should be automatically updated, and automatically displayed, if desired. When an icon is selected by the user, its position and status information should be displayed.

The system must have features for automatic or manual position selection for reporting purposes. That is, the user will have the capability to manually enter his position by choosing a point on the map or automatically from his POS/NAV device. Also, the system shall provide the option to manually or automatically transmit and receive position reports. Position reports must identify the sender and his location, heading, speed, and altitude.

Two conditions will cause automatic position updates to be transmitted at selectable time intervals: 1) if the platform changes its position by more than some specified amount, and 2) a maximum time span, regardless of platform movement.

The TDS must include a navigation support capability. At a minimum this capability should allow for the graphical generation of routes and waypoints, current speed and heading, time/distance information, and a steer-to function which informs the driver which direction to steer in order to return to a designated route.

2. Digital Map Display

The TDS shall provide the capability to load and display standard DMA map products at the scale of 1/50,000. Included will be the desired capability to scroll and the required capabilities to zoom in/out (1/25,000 and 1/100,000), jump to a manually selected point, and convert between latitude/longitude and Universal Transmeridian (UTM) references. The TDS shall also display map datum information.

3. Imagery Reception and Display

It is desired that the TDS possess the capability to receive, integrate, and display satellite and aerial imagery. Images should be georeferenced and displayed with explanatory textual information. A terrain analysis capability should exist to facilitate navigational planning.

B. COMMUNICATION MANAGEMENT

Communication management is the process of placing critical information at the right place, at the right time, and in a form that influences appropriate action (FMFM-3, 1994). To achieve effective communication management, the TDS must meet the following requirements, as identified in the Army's Request for Proposal (RFP) for Brigade 96.

The TDS must provide a highly flexible, dynamic

networking capability that addresses and routes messages with little or no user intervention. Network flexibility must allow independent TDS units to enter and leave communication nets quickly. This allows the network to accommodate changes in task organization and mission.

When a TDS enters or leaves a net, all users on that net must be made aware of the change. The TDS shall dynamically monitor all communication networks of which it is a part and create a listing, by network, of active users. This listing must be updated for additions and deletions automatically, and should be available, by query, to the user.

The TDS must be responsive to changes in the role it may play. For example, should a commander's vehicle be destroyed, the TDS on the platform he assumes must be able to accommodate the increased communications burden. It must easily be re-programmed to automatically forward data to different addresses. This is accomplished by allowing the user to select pre-programmed individual addressees, addressee groups, and broadcast groups.

The TDS shall provide the user a visual notification upon the receipt of all messages. An audible notification is desirable. This would especially be useful in identifying messages designated by the sender as requiring a WILCO (will comply). Additionally, the TDS will provide the ability to furnish acknowledgment of the receipt of messages. However, the TDS will also provide the capability to monitor a network without providing acknowledgements so as not to interfere with the data transmissions within the net.

The TDS must permit non-attended receipt of messages and overlays. All messages, read and unread, must be stored and easily recalled. Messages/overlays should be saved to non-volatile memory on a first in/first out, message priority queued basis. This would allow high priority messages to take precedence over more recently received but lower priority

messages. Also, the TDS will display a message to the user when more than a user-specified number of unread messages are in the queue. Finally, the TDS shall not attempt to initiate a data transmission that would interfere or conflict with voice transmissions.

C. EXECUTION OF COMMAND AND CONTROL

Joint Pub. 1-02 defines command and control as:

> ... the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.

An effective TDS will support this definition and aid in reaching the ultimate objective of command and control, to achieve unity of effort and increase the tempo of operations. The TDS must provide the capability to execute command and control with a minimum amount of user interface. It must support the rapid generation, transmission, and undistorted receipt of overlays and messages necessary to execute commands. These overlays and messages should include autofilled entries which provide, at a minimum, unit identification, date-time group, location, and message number. The TDS software shall support, at a minimum, the overlays and messages described below.

1. Overlays

The TDS software shall create, move, copy, delete, print, store, transmit, and display standard military overlay information and free text on a digital map. Desired is the capability to free-hand draw graphic and textual entries on an

overlay. The TDS must support, at a minimum, the creation of the following overlays: maneuver, intelligence, obstacle and fire support. The overlays shall be able to be displayed individually or in combinations that integrate to show a more complete picture of the battlefield. In order to reduce data traffic, the software must be designed in a manner that allows the transmission of only changes to current overlays. However, the TDS should automatically send complete overlays to new members entering the net, and should include an overlay update command that transmits the most recent of each overlay type to the designated receiver or receivers in one package. Minimum overlay content is listed below.

a. Maneuver Overlay

The maneuver overlay shall address:

- Friendly unit designator, type, and size (e.g., designator= 5th Marines, 1st Tanks, etc.; type= Armor, Headquarters, etc.; size= platoon, battalion, etc.)
- Weapon types (e.g., tank, artillery, automatic weapon, etc.)
- Control points (e.g., waypoint, checkpoint, observation point, Target Reference Point (TRP), etc.)
- Control Lines (e.g., phase lines, boundaries, axis of advance, etc.)
- Areas (battle position, objective, no fire zone, etc.)

b. Intelligence Overlay

The intelligence overlay shall address:

- Enemy unit designator, type, and size
- Enemy weapon types

c. Obstacle Overlay

The obstacle overlay shall address:

- Mines (anti-tank, anti-personnel, phony, etc.)
- Vehicle obstacles (tank ditches, berms, posts, blockades, etc.)
- Personnel obstacles (wire, booby-traps, etc.)
- Identified passage points through obstacle belts and natural obstacles

d. Fire Support Overlay

The fire support overlay shall address:

- Identification and locations of friendly fire support units (artillery, naval gunfire, mortars, close air support, and close-in fire support)
- Permissive fire support coordination measures (coordinated fire line, free fire area, etc.)
- Restrictive fire support coordination measures (no fire area, airspace coordination area, etc.)
- Other control measures (boundaries, tactical areas of responsibility, etc.)
- Targets (planned fires)
- Ammunition supply points
- Desired are range indicators for mortar and artillery types

2. Messages

The TDS shall create, display, receive, prioritize, copy, edit, delete, print, store, and transmit data supporting messages. Templates, with prompts to assist the operator, shall be created for the following message types.

- Spot Report
- Situation Report (SITREP)

- Warning Order
- Fragmentary Order (FRAGO)
- Contact Report
- Call for Fire
- Close Air Support
- Close-in Fire Support
- Air Alert
- NBC Reports and Alerts
- Enemy Prisoner of War (EPW) Report
- MEDEVAC Message
- Fire Support Plan (to be attached to the fire support overlay)

A far target designation capability is required to automatically generate and display the eight digit grid coordinate to any target that is designated by the platform's laser rangefinder. Further, the lasing event should automatically generate a spot report, with the position of the target included, to be transmitted on command.

Additionally, a free text message capability, with the capability to cut and paste from a free text document, is essential.

D. COMBAT SUPPORT AND COMBAT SERVICE SUPPORT

The TDS shall provide the user with combat support and combat service support capabilities to include battle planning support, logistics information support, and administrative support. This capability is intended to be used when planning and coordination time are available. The following overlay and messages shall be included to support this facet of battlefield planning and coordination.

1. Overlay

The TDS software shall provide for the display on an overlay of results of reconnaissance (e.g., route, obstacle, etc.), commander's critical information requirements, and combat replay (an archival capability to display the last user designated period of overlays).

2. Messages

The software shall support, at the minimum, the following messages:

- Logistics Reports (Classes I through IX)
- Maintenance Support
- Medical Information
- Personnel Status Report (PERSTAT)
- Personnel Battle Loss Report
- Operations Order (OPORD)
- Commander's Critical Information Requirements (CCIR)

Desired is the capability for the TDS to automatically recognize vehicle logistic requirements and operational status. The flexibility to manually or automatically report logistic status should exist. Further, at each level of command, the capability should exist to accumulate reports from the next subordinate level, consolidate them, and send them on a manual or automatic basis.

E. GENERAL REQUIREMENTS

1. The TDS must allow the flow of information without regard to message format or protocols. This requirement makes clear the need for the use of common message formats and communication protocols on the battlefield.

2. Voice and data must be able to be transmitted in such

a manner that one transmission does not interfere with the other. This should be transparent to the user.

3. The TDS must not degrade the mobility or maneuverability of the platform on which it resides. It must be capable of operating on the move and should not degrade the ability of any host platform to perform its primary function.

4. TDS software will be "user friendly" to facilitate operation in a tactical environment. The use of modularity and an open architecture in system design is encouraged to facilitate rapid upgrades.

5. Measures to reduce electronic countermeasure susceptibility must be considered.

6. Information security measures must be considered.

7. While the interoperability with all DoD equipment is desired, the priority of interoperability among the Services is: USMC systems, U.S. Navy systems, Joint Task force Commander C4I systems, and U.S. Army and U.S. Air Force systems.

8. A remote display capability is desired. This would allow the vehicle commander to manipulate the TDS from multiple positions in the vehicle.

The above requirements are the base by which the two tactical data systems included in this thesis will be measured. Areas in which the systems exceed requirements or prove deficient will be considered in the comparison. Presented in the following chapter are the detailed physical and functional descriptions of each system. This data will be matched up with the requirements to reveal the level of conformity in each system.

V. DESCRIPTION OF SYSTEMS

The purpose of this chapter is to provide the information necessary to allow the reader to adequately understand the functional and physical operation of the TCO Armor and the MACCK. The functional description of each system as a whole is accompanied by the physical description of each major system component. While the MACCK has been fully developed and prototyped, the TCO Armor is still in its early developmental phase. As such, portions of the TCO Armor's functional and physical description will be of the system as it is currently envisioned.

A. TACTICAL COMBAT OPERATIONS (TCO) SYSTEM (ARMORED VEHICLE VARIANT)

1. Functional Description

The TCO Armor is end-user equipment composed of ruggedized computer hardware, software, and input/output devices to provide automated data support for armored vehicle commanders. By providing functionality in the areas of situational awareness, communication management, execution of command and control, and combat support and combat service support, the TCO Armor meets the encompassing requirement of allowing combat and combat support forces to more efficiently exchange information and interact effectively on the battlefield. Discussed below is the functional description of the TCO Armor, relative to the four functional areas previously identified.

a. *Situational Awareness*

In keeping with the previously defined situational awareness requirements, the TCO Armor includes a Global Positioning System (GPS) interface to provide own loçation data, in latitude/longitude or UTM reference, to a one meter accuracy level. This information, presented as an icon on the calculated position on a standard DMA map, can be viewed on

the high resolution, multi-color display included in the system. The capability will exist to zoom in and out from a 1/50,000 scale map to 1/25,000 and 1/100,000.

Due to the networked nature of the digital battlefield, this information can be transmitted to any other compatible unit that is active on the network. This fully interactive system also allows for the positions of other specific platforms or units on the network to be received, automatically or on demand, and displayed. The display is updated automatically at a user-specified interval, or on demand.

TCO Armor allows for the automatic or manual entering of position data in formatted reports. This gives the user the flexibility to type in his location, move the cursor to a point on the map and select it for his location, or allow the position of his own-unit icon to be automatically entered.

The TCO Armor provides navigation support by allowing the user to program graphically displayed routes and sequentially numbered waypoints. Utilizing the GPS interface, the heading and distance from the platform's current position to a selected waypoint can be calculated. This information will be displayed for the vehicle commander on his display unit.

b. Communication Management

TCO Armor provides the following communication management capabilities:

- Creates a digital network by interfacing with compatible units via SINCGARS and/or PLRS
- Allows the user to solicit manually information as to which users are active on the net
- Provides the user a visual and, as envisioned, an audible notification of incoming messages

- Provides the capability for voice transmissions to override data transmissions

- Stores all messages and overlays to non-volatile memory and indicates to the user the amount of remaining disk capacity

- Provides an auto-forward capability which allows messages and overlays to be automatically forwarded to designated addresses upon receipt.

c. Execution of Command and Control

TCO Armor supports the execution of command and control in the following ways:

- Creates, moves, copies, deletes, prints, stores, transmits, receives, updates, and displays standard military overlay information and free text on a digital map

- Includes autofilled entries on overlays and messages which include originating unit identification, date-time group of overlay/message transmission, originating unit location, and message number

- Creates and manipulates maneuver, intelligence, obstacle, and fire support overlays

- Integrates separate overlays

- Creates, displays, receives, prioritizes, copies, edits deletes, prints, stores, and transmits data supporting messages

- Creates templates for the required message types listed in the previous chapter

- Provides a free text message capability

- Eliminates redundancy of reports that cite the same event by utilizing algorithms to determine if multiple users are reporting the same target

- Provides a far-target designation capability that automatically generates and displays the eight digit grid coordinate of the lased target

d. Combat Support and Combat Service Support

TCO Armor provides the following combat support and combat service support capabilities:

- Displays on an overlay results of reconnaissance, commander's critical information requirements, and combat replay
- Supports the creation, edit, and transmission of the required combat and combat service support messages listed in the previous chapter

2. Physical Description

The TCO Armor, as currently envisioned, consists of the following primary components:

- Computer Unit
- Hard Disk Drive (HDD)
- Chassis
- Display and Keyboard Unit
- GPS Receiver
- Laser Rangefinder with Magnetic Compass

All components and the manner in which they interface are presented in Figure 1.

a. Computer Unit

The computer unit will be a UNIX-based system consisting of three 6U VME boards and a VME bus backplane, which as a unit, will fit into a rugged MIL-SPEC 3-slot, 6U, VME card cage. The three boards are described below.

(1) Central Processing Unit. The CPU is an HP series 9000, Model 743i single board computer. This 6U X 160mm VME circuit card provides numerous interfaces, to include one small computer systems interface (SCSI) for interface with the HDD, two RS-232 serial ports, one parallel port, one ethernet port, one keyboard port, and one trackball

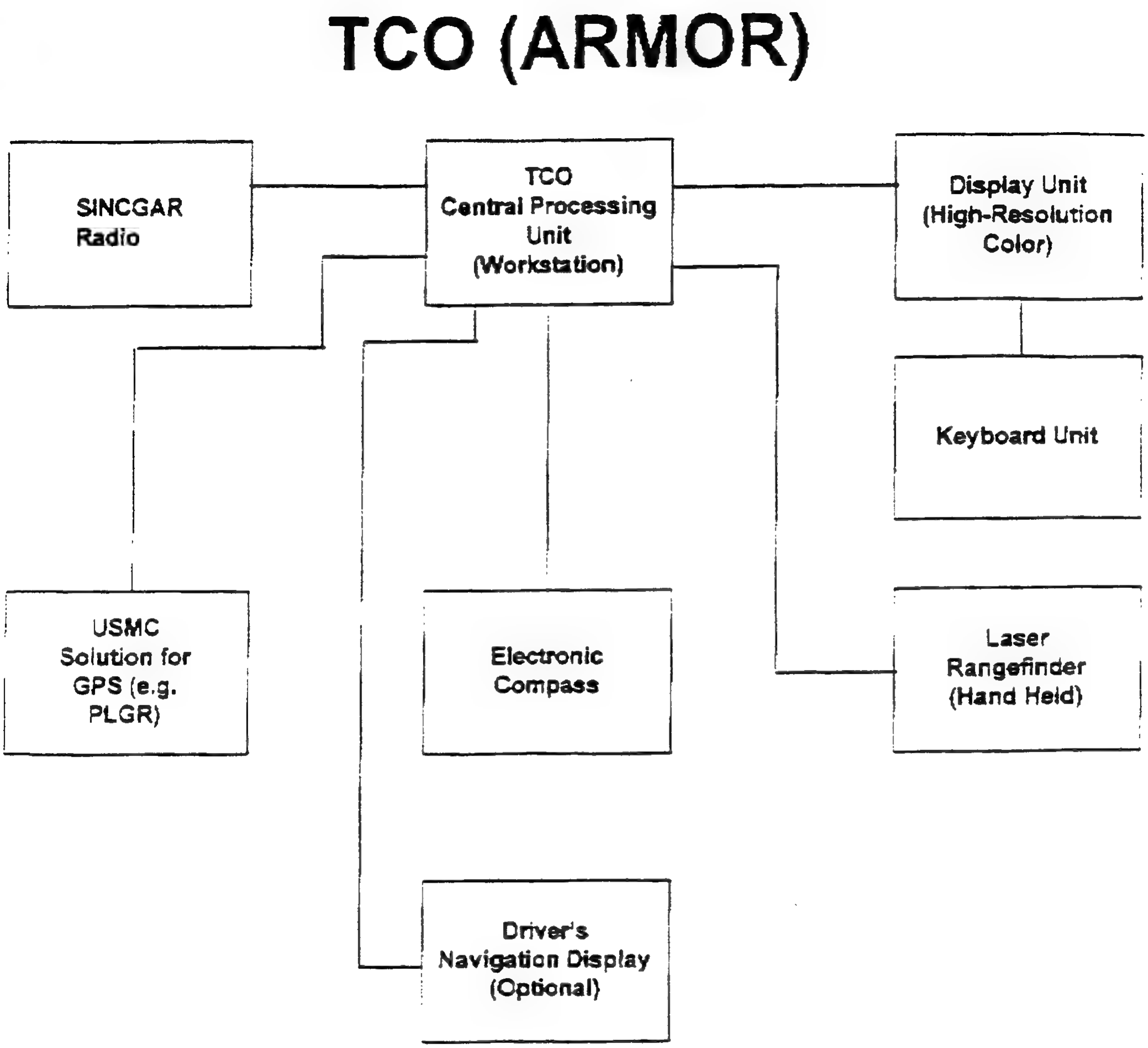

Figure 1. TCO Armor

port. It features a 64MHz PA-RISC 7100LC processor with built-in high-performance floating point co-processor with a 256KB instruction/data cache for faster program execution times. The Model 743i can operate at temperatures ranging from -5 to 55 degrees Celsius and can be stored at a temperature range of -40 to 70 degrees Celsius. (Hewlett-Packard, 1994)

(2) Graphics Processor. The graphics processor is the Vgs-882, a high performance color graphics server based on the LSI Logic LR33020 GraphX processor, contained on a single 6U VME board. The Vgs-882 has the ability to drive color active-matrix liquid crystal displays (LCDs), in addition to a wide range of analog monitors (Vigra, 1993)

(3) Tactical Communications Interface Module (TCIM). The TCIM is a portion of the Army Tactical Command and Control Systems (ATCCS) Common Hardware and Software (CHS) program. The TCIM, configured for use with the TCO Armor as a 6U VME circuit card, is a programmable four-channel multipurpose communications device capable of communicating with a wide range of tactical communications equipment, to include the SINCGARS. Interfacing with both voice and digital communications devices, the TCIM is ideal for the transmission and reception of secure and non-secure information for the TCO Armor.

b. Hard Disk Drive

The HDD will utilize solid state technology to provide a more robust 2GB storage capability. Although this quantity of storage is not yet achievable with solid state technology, industry experts predict that a 2GB storage capacity will be reached in 1995. The drive will be mounted in a removable canister which can be inserted into a receptacle which is permanently mounted inside the system chassis using vibration and shock isolators.

c. *Chassis*

The system chassis is the ruggedized box that will hold the computer unit and HDD. Included in the chassis will be a heat exchanger, fans to induce forced air circulation, a DC to DC power supply with heat sink, an AC to DC power supply, a battery pack with battery charging circuitry, and a recessed connector panel and power switch. The chassis will be mounted to the receiving platform using vibration and shock isolators.

d. *Display and Keyboard Unit*

The display and keyboard will function as the primary user interface for the TCO Armor. The keyboard will provide an alphanumeric data entry capability. Included on the keyboard will be a trackball to facilitate the user interface. While normally mounted as a single unit, the display and keyboard can be separated so that each component can be moved in and around the host platform. This provides the user an enhanced flexibility by not requiring that the operation of the TCO Armor take place in a fixed crew position.

The display unit will be a 10.5 inch diagonal, high resolution, multi-color capable, liquid crystal display (LCD) panel with backlight assembly and power source. Included will be an analog to digital interface and a touch pen assembly for ease of data input or command selection. A series of "hot switches," each assigned a specific function, will be located on the border of the display panel.

e. *GPS Receiver*

The GPS receiver to be used with the TCO Armor is the AN/PSN-11 Precision Lightweight GPS Receiver (PLGR, "plugger"). The PLGR, now in production by Rockwell,. is a handheld or vehicle mountable unit with selective availability for instantaneous 10 meter location determination, one data port, one crypto port, and a five channel capability.

f. Laser Rangefinder with Magnetic Compass

The laser rangefinder with integrated compass that is currently being considered for use with the TCO Armor is the AN/PVS-6 Melios. The Melios is a seven pound handheld binocular and laser rangefinder with integrated display and data port. However, the compass portion of the unit, the combined vertical and azimuth modification (CVAM), will not be available until mid-1995. When included, the Melios will have the capability of giving an integrated range, azimuth and vertical angle to the display and data stream.

B. MULTI-APPLICATION COMMAND AND CONTROL KIT

1. Functional Description

The following functional description of the MACCK was provided by General Dynamics Land Systems Division.

The MACCK is a C3I system which prepares, collects, organizes, displays, and disseminates pertinent battlefield C3I information to task force assets at the battalion echelon and below. It provides a modular and flexible integration package designed to accommodate multiple vehicle installation requirements while maintaining a seamless command and control interface. Additionally, the MACCK provides a number of different functional performance levels which allow users to tailor the MACCK capabilities to the unique role of each specific vehicle installation. The three baseline capability packages are:

- Command and Control Package
- Autonomous Navigation Package
- Far Target Designation Package

a. Command and Control Package

The Command and Control Package provides the essential command and control capabilities necessary to integrate a vehicle platform on the digital battlefield. This package supports multiple digital communications protocols and message sets necessary to digitally integrate maneuver, aviation, artillery, and combat support assets.

Interfacing with the SINCGARS and the Precision Lightweight GPS Receiver (PLGR), the Tactical Display Unit and the Command and Control Electronics Unit provide the command and control functions summarized as follows:

- IVIS Protocol (See Chapter II for information on IVIS)
- IVIS Message Sets (Reports and Overlays) (These include all reports and overlays defined in the requirements portion of the thesis)
- TACFIRE Protocol (for interface with Army Field Artillery)
- Field Artillery Message Subset
- Logistics Report
- Automatic Position Report Transmission
- Grid Map for Mutual Position Location
- Automatic Network Control for TACFIRE and IVIS

b. Autonomous Navigation Package

The Autonomous Navigation Package, through the addition of an Inertial Reference Unit, a Distance Measurement Unit and a Driver's Navigation Display, provides the crew an autonomous capability to navigate the vehicle without external aide. This capability implements a dead reckoning algorithm to continuously calculate vehicle position and operates independent of the GPS. Thus, if the GPS signal is unavailable, full navigation and route planning capabilities

are retained.

The Inertial Reference Unit provides vehicle position and heading based on an earth and vehicle interface to provide distance travelled. Since Inertial Reference platforms are subject to drift with time and temperature, an interface to the Global Positioning System is used to periodically update the IRU to eliminate such drifts.

Using the heading information of the IRU and waypoint information entered into the Tactical Display Unit by the commander, the MACCK electronics computes a trajectory to the waypoint. This information, presented to the driver in an alphanumeric format, guides him to the proper route to proceed to that waypoint. Using such a system, the driver is freed to use the terrain and foliage features to mask the vehicle. He can be confident that the computer is maintaining a continuing path to his desired objective.

c. Far Target Identification Package

The Far Target Identification Package provides an interface to a vehicle's Laser Rangefinder (LRF) and Turret Position Encoder. Such an interface allows targets to be lased from a vehicle and displayed on the Tactical Display Unit for automatic inclusion in reports and overlays.

The Inertial Reference Unit provides vehicle hull heading. The Turret Position Encoder provides the relative rotational position of the turret with respect to the hull. The Laser Rangefinder gives distance to the target. Vector calculations result in the position of the target with respect to the originating vehicle. Since this computation is done within MACCK, the position of the target is automatically displayed on the Tactical Display Unit. The lasing event also triggers the automatic generation of a spot report by the system. The commander has a one-button ability to send the enemy position to friendly units.

The MACCK analyzed in this thesis possesses the full

functionality described above.

2. Physical Description

The MACCK is comprised of the following non-government furnished components:

- Command and Control Electronics Unit
- Tactical Display Unit
- Inertial Reference Unit
- Distance Measurement Unit
- Driver's Navigation Display

The SINCGARS radio, PLGR, Laser Rangefinder, and Turret Position Encoder are government furnished. All components and the manner in which they interface are presented in Figure 2.

a. Command and Control Electronics Unit

The electronic modules of the Command and Control Electronics Unit include the following elements:

- System Processor - or the Bus Controller/Remote Terminal Board
- Tactical Graphics Module - drives graphics to the Tactical Display Unit
- Extended Memory Module
- Serial Input/Output Module - provides an interface to the external sensors
- Two Radio Interface Boards

b. Tactical Display Unit

The Tactical Display Unit features a high-resolution, multi-color capable panel and includes the following components:

- Keypad - Alpha-numeric entry
- Thumb Controller - Cursor control on the display screen

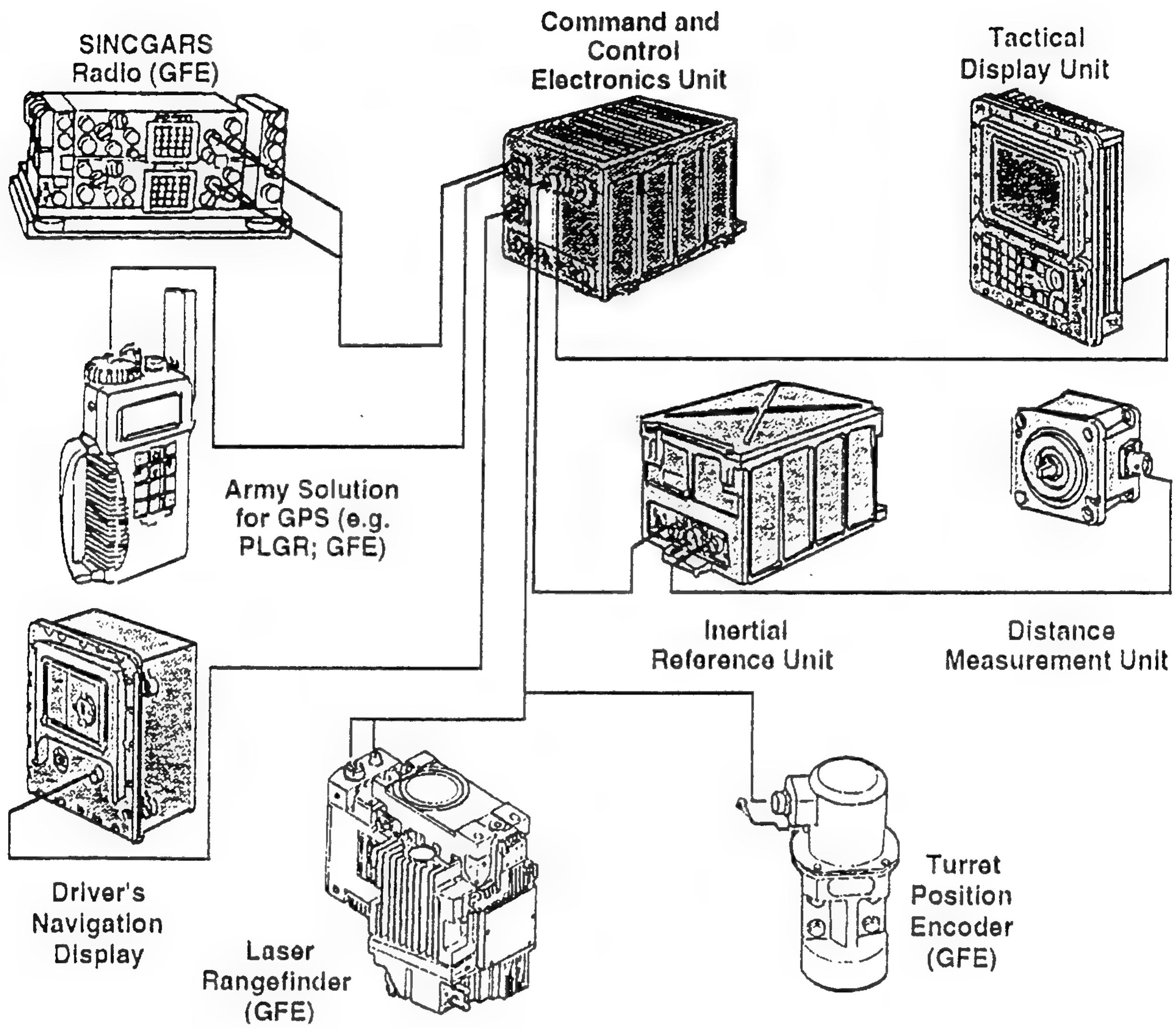

Figure 2. MACCK

- 4-Way Switch - Adjustment Functions (e.g., brightness)
- Miscellaneous Switches - For example, On/Off

A Panel Interface Module will be added to the TDU to interface to the switches and keypad.

c. Inertial Reference Unit

The Inertial Reference Unit interfaces with the Command and Control Electronics Unit to provide it with vehicle position and heading. It uses a dead reckoning algorithm to continuously calculate vehicle position.

d. Distance Measurement Unit

The Distance Measurement Unit interfaces with the Inertial Reference Unit to provide it with distance traveled information. This data is necessary for position calculation.

e. Driver's Navigation Display

The Driver's Navigation Display unit is a mono-color display panel located in the driver's compartment that presents navigation information. It presents to the driver, in an alphanumeric format, the magnetic azimuth required to steer to a predefined waypoint.

VI. LIFE CYCLE COST ESTIMATES

The purpose of this chapter is to highlight the difference in cost, to the Marine Corps, between the TCO Armor and the MACCK. To achieve this, only cost differences resulting from the procurement of alternative tactical data systems are considered.

For example, regardless of whether the TCO Armor or the MACCK were procured by the Marine Corps, manpower and training costs associated with that procurement would be equal. The TCO Armor and the MACCK are designed to accomplish the same mission, supported by an equal amount of comparably trained personnel. Therefore, the manpower and training costs normally considered in a life cycle cost estimate are disregarded in this comparison.

On the other hand, the procurement costs associated with the different systems do vary. This is a result of the different unit costs and number of spares required for each system. Because these costs differ, they are included in the life cycle cost comparison.

The life cycle cost of a system reflects all costs incurred by that system from project initiation through termination. The following equation reflects this cumulative cost and is used as the model for determining the life cycle cost of the TCO Armor and the MACCK:

LCC = R&D + PROCUREMENT + OPERATIONS/MAINTENANCE.

A. GENERAL ASSUMPTIONS

The following assumptions hold for the life cycle cost estimates of the TCO Armor and the MACCK.

- That the life cycle cost estimates are based upon a one-time buy of 130 units.

- That the life cycle cost estimates are based upon an operating rate of 3952 hours/unit/year (1/3 of the year at 24 hours/day, 7 days/week, and 2/3 of the year, 6 hours/day, 5 days/week).

- That the service life of each TDS is 15 years.

- That the hourly repair cost composite rate for 1st-3rd echelon maintenance is the same for each TDS.

- That the required availability rate for each TDS is 90 percent.

- That procurement costs are represented in current year dollars, while operations/maintenance costs are discounted over the 15 year life of the systems at a seven percent discount rate. (This discount rate is taken from OMB Circular A-94.)

- That manpower and training costs will be comparable regardless of the TDS procured. Therefore, these costs are not considered in this comparison.

- That the Marine Corps would negotiate comparable procedures and costs for contractor maintenance of hardware items regardless of the TDS procured. Therefore, maintenance costs for depot level maintenance are not considered in this comparison.

- That only second and third echelon corrective maintenance costs are considered in this comparison. All other costs related to maintenance (i.e., preventive maintenance costs, test equipment costs) are assumed to be the same for each TDS.

- That the mean time to repair reflects the only difference in maintenance cycle time between each TDS.

- That test and evaluation costs would be comparable for each TDS. Therefore, they are not considered in this comparison.

B. TCO ARMOR LIFE CYCLE COST

1. Research and Development Cost

The TCO Armor, as envisioned, is an extension of the existing TCO program. As such, funding for its research and development is provided by the Marine Corps, through the TCO

Project office.

For the purpose of this comparison, research and development costs equal the costs incurred in developing a hardware prototype plus costs required to modify existing TCO software to provide the functionality required of a TDS:

R&D COST = HARDWARE R&D + SOFTWARE MODIFICATION.

Because the TCO Armor is currently in the research and development phase, the full costs associated with hardware prototyping have yet to be determined. The amount budgeted for this endeavor is $250,000. This is the figure used in the comparison.

Software modification involves the effort to enhance existing TCO software to include the functions required of a TDS that is used at levels below battalion. Expert opinion serves as the basis for an estimated one-time cost of $400,000 (Price, 1994).

R&D Cost = $250,000 + $400,000

The R&D cost for the TCO Armor is $650,000.

2. Procurement Cost

The procurement cost for the TCO Armor is calculated by adding the number of units procured with the number of spare units required to support the fleet for a given number of hours of operation, and multiplying this total by the unit cost:

PROCUREMENT COST = (UNITS + SPARES) X UNIT COST.

The number of units used in this comparison is 130. While 100 or 1000 could just have easily been used to illustrate the cost difference between the TCO Armor and the MACCK, 130 reflects the number of units required to outfit the tanks in two Marine Corps tank battalions and one training company.

Spare quantity determination is a function of a probability of having a spare available when required, the reliability of the item in question, and the quantity of items

used in the system (Blanchard, 1992). In this comparison, the number of spares is based on a required operational availability level of 90 percent with a 100 hour maintenance turnaround time. Mean time between failure (MTBF) is the measure used to reflect the reliability of each TDS, while the quantity of items used in the Marine Corps system is 130.

Figure 3 presents a nomograph, originally presented in NAVSHIPS 94324, and reprinted in Benjamin S. Blanchard's Logistics Engineering and Management, which simplifies the determination of spare quantities. The number to be plotted on the left side of the nomograph is determined by multiplying the number of items in the system, K, by the number of failures/1000 hours, lambda, by the maintenance turnaround time, T. The right side of the nomograph, P, represents the probability of having a spare available when required. This probability is equivalent to the operational availability rate. To determine the number of spares required, the product of K, lamda, and T is connected to the operational availability rate, P. The point where this line crosses the "Number of Spares" curve represents the quantity of spares required to support the fleet, given a 100 hour maintenance turnaround time and a 90 percent required availability rate.

For the TCO Armor K = 130

lambda= 0.00164

T = 100

P = 0.90

Using the nomograph, approximately 28 spares are required.

The system unit cost is the sum of the TCO Armor's individual component costs. In most cases, vendor quotes provided the source for the individual component costs. However, expert opinion was used to estimate the costs of the system chassis and hard disk drive (Price, 1994). The component costs added to a total of $55,500.

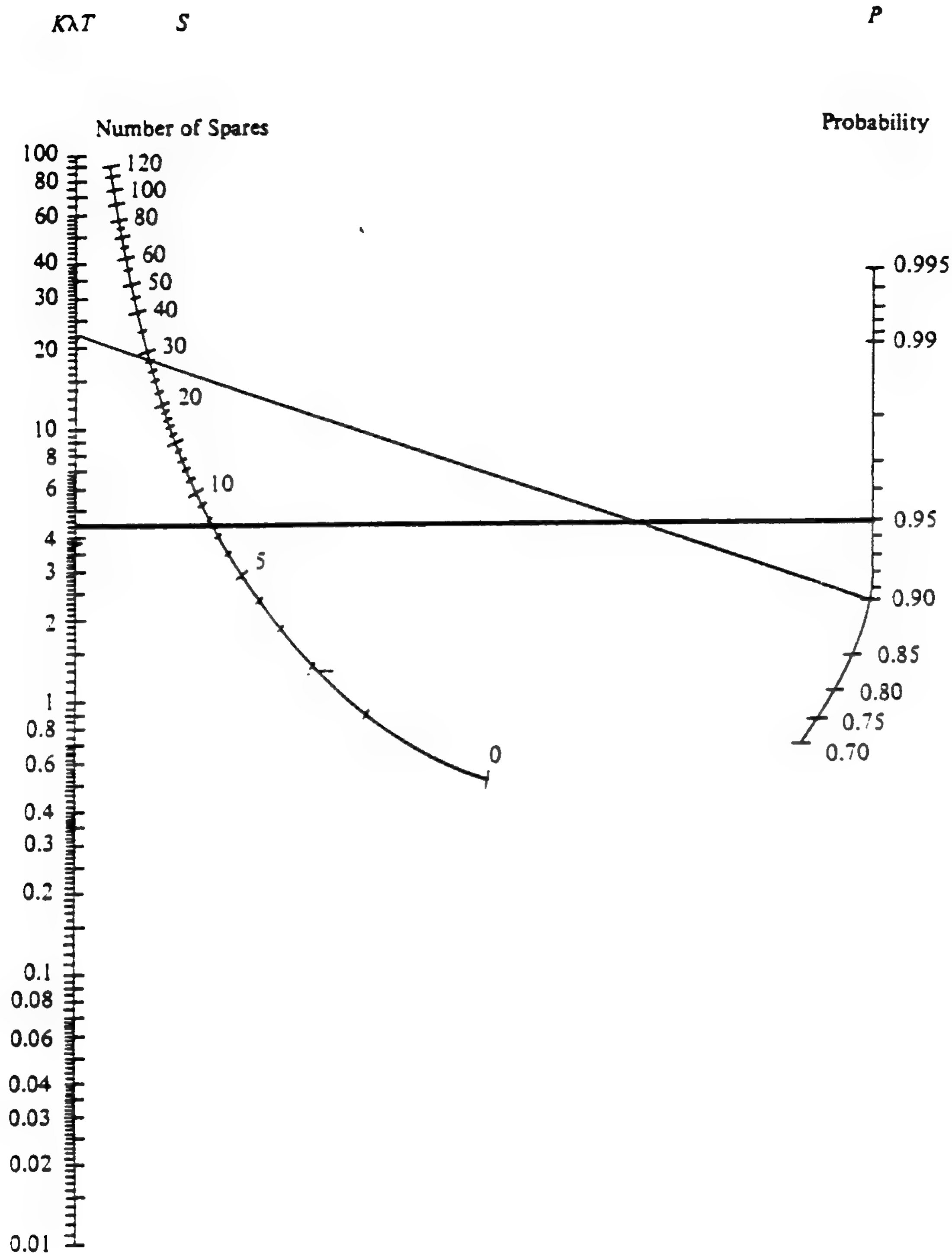

Figure 3. Spare Quantity Requirement Nomograph
From Ref. (Blanchard, 1992)

Procurement Cost = (130 + 28) X $55,500

The procurement cost for the TCO Armor is $8,769,000.

3. Operations and Maintenance Cost

In the pursuit of defining the cost differences between the TCO Armor and the MACCK, this portion of the life cycle cost estimate focused on hardware and software maintenance costs. The primary cost driver differences in this category were system MTBF and mean time to repair (MTTR).

Hardware maintenance costs were derived by determining the number of system failures (based on MTBF) for a given number of operating hours. The MTBF for the TCO Armor, 609 hours, was calculated by integrating the MTBF of each system component. By dividing this number into total operating hours (# of units x op hours/unit/year x service life) the total number of system failures over the service life of the systems was determined. This figure, multiplied by the MTTR of the TCO Armor, gives the total amount of time that corrective maintenance is actually being conducted. Preventative maintenance and other factors which contribute to the maintenance cycle time of a TDS were assumed to be equal for each system. The product of the corrective maintenance time and the hourly repair cost provides the hardware maintenance cost for the TCO Armor. This cost, discounted at 7% for 15 years, is $458,646.

The software maintenance cost estimate is based on expert opinion. It is estimated that future software maintenance costs for the TCO Armor will equal approximately ten percent of the software maintenance costs for the TCO. The TCO office currently pays $1,000,000/year for software maintenance. Over the 15 year service life of the TCO Armor software maintenance costs will equal $1,500,000. (Carlson, 1994) Although General Dynamics was unable to make an equivalent estimate for the MACCK, it can be assumed that the Marine Corps would negotiate a similar contract for software maintenance regardless of the

system procured. Therefore, software maintenance costs will not be considered in this life cycle cost estimate.

The discounted operations and maintenance cost for the TCO Armor is $458,646.

Figure 4 provides a numerical summary for the life cycle cost of the TCO Armor.

TCO Armor

Units	130
Unit Cost	$55,500.00
Spares*	28
Service Life*	15
MTBF*	609
MTTR*	1
Repair Cost*	$100.00
Hours/Unit/Year	3952
Total Op Hours	513760
Discount Rate	7.00%

R&D COST

R&D Cost = Hardware R&D + Software Modification
= $250,000.00 + $400,000.00
= **$650,000.00**

PROCUREMENT COST

Proc. Cost = (Units + Spares) x Unit Cost
= (130 + 28) x $55,500.00
= **$8,769,000.00**

OPERATIONS AND MAINTENANCE COST

Ops./Maint. Cost = Hardware Maint. Cost
= $1,265,418.72
Discounted = **$458,646.00**

LCC TCO ARMOR = R&D + PROCUREMENT + OPS/MAINTENANCE
= **$9,877,646.00**

*Spares = Number of spare units required to support the fleet for 100 operating hours
*Service Life = Service life in years
*MTBF = Mean Time Between Failure in hours
*MTTR = Mean Time To Repair in hours
*Repair Cost = Fixed hourly rate for maintenance cost
*Software Maintenance = Cost to maintain and upgrade software over the service life of the system

Figure 4. Life Cycle Cost Estimate for the TCO Armor

C. MACCK LIFE CYCLE COST

1. Research and Development Cost

General Dynamics has funded the research and development effort for the MACCK through contractual agreements with the Army and self-investment. From the Marine Corps point of view, these are sunk costs. As such, they are not considered in this life cycle cost comparison.

2. Procurement Cost

Procurement costs for the MACCK are computed in the same manner as for the TCO Armor. The same method of determining the number of spares required for fleet support that was used for the TCO Armor indicated a quantity of 18 MACCK system spares would be required for a 90 percent operational availability rate.

For the MACCK K = 130

lambda= 0.001

T = 100

P = 0.90

The unit cost of $75,000 was provided by General Dynamics representatives (Hill, 1994).

Procurement Cost = (130 + 18) X $75,000

The procurement cost for the MACCK is $11,100,000.

3. Operations and Maintenance Cost

The operations and maintenance cost for the MACCK was also computed in the same manner as for the TCO Armor. A MTBF of 1000 hours and MTTR of .5 hours for the MACCK was provided by General Dynamics representatives. These figures were based upon prior experience with similar equipment that was tested in simulated combat conditions.

As discussed above, software maintenance costs for the MACCK will not be considered in this life cycle cost estimate.

The discounted operations and maintenance cost for the MACCK is $139,658.

Figure 5 provides a numerical summary of the life cycle cost estimate for the MACCK.

MACCK

Units	130
Unit Cost	$75,000.00
Spares	18
Service Life	15
MTBF	1000
MTTR	0.5
Repair Cost	$100.00
Hours/Unit/Year	3952
Total Op Hours	513760
Discount Rate	7.00%

R&D COST
0

PROCUREMENT COST

Proc. Cost = (Units + Spares) x Unit Cost
= (130 + 18) X $75,000.00
= **$11,100,000.00**

OPERATIONS AND MAINTENANCE COST

Ops./Maint. Cost = Hardware Maint. Cost
= $385,320.00
Discounted = **$139,658.00**

LCC MACCK = R&D + PROCUREMENT + OPS/MAINTENANCE
= **$11,239,658.00**

*Spares = Number of spare units required to support the fleet for 100 operating hours
*Service Life = Service life in years
*MTBF = Mean Time Between Failure in hours
*MTTR = Mean Time To Repair in hours
*Repair Cost = Fixed hourly rate for maintenance cost
*Software Maintenance = Cost to maintain and upgrade software over the service life of the system

Figure 5. Life Cycle Cost Estimate for the MACCK

VII. SYSTEMS COMPARISON AND RECOMMENDATIONS

A. REQUIREMENTS COMPARISON

The initial objectives of this study were to justify the need for the Marine Corps to provide a digital command and control capability at the individual platform level and to determine which of the systems analyzed in this thesis could meet a given set of requirements in the more cost effective manner. As the research on the second objective progressed, it became clear that neither system, as currently configured or envisioned, could fully meet all of the requirements set forth. Therefore, the focus of the study shifted to determining which system could <u>best</u> meet the given requirements in a reliable and cost effective manner.

A system comparison requirements matrix (see Figure 6) was developed to more easily judge the merits of each system. Requirements are listed in the left column of the table with the following two columns indicating whether or not each system was able to meet them. The final column identifies the system that best meets the requirement.

In keeping with the approach of focusing on key differences of the systems, the requirements that are not equally met by each system will be briefly discussed.

1. Situational Awareness

Although both systems meet the situational awareness requirements put forth, the MACCK is deemed superior in this category. The rationale for this choice lies in the superior navigational system possessed by the MACCK. The onboard inertial navigation system makes reliance on a GPS or PLRS unnecessary. Although the MACCK uses GPS to update its inertial system, the system is not dependent upon an essentially external source for positional and navigational information. The redundancy of an onboard inertial navigational system and GPS gives the MACCK a greater degree

REQUIREMENTS	TCO ARMOR	MACCK	BEST SYSTEM
Situational Awareness	X	X	MACCK
Communication Management	—	X	MACCK
Command and Control	X	X	Equal
Combat Support and Combat Service Support	X	X	Equal
Free Flow of Information	—	—	Equal
Non-Interfering Voice and Data Transmissions	X	X	Equal
No Mobility Degradation	X	X	Equal
"User Friendly" Software	X	X	MACCK
Reduce Electronic Counter-measure Susceptibility	—	X	MACCK
Consider Information Security	X	X	Equal
Interoperability Priority	X	—	TCO
Remote Display	X	—	TCO

(X) = Meets requirement

(-) = Does not meet the requirement

TCO = TCO Armor best meets the requirement

MACCK = MACCK best meets the requirement

Equal = Neither system dominates the other in the requirement

Figure 6. Requirements Matrix

of reliability and makes it a superior system in providing situational awareness.

2. Communication Management

The fact that the TCO Armor does not meet all communication management requirements while the MACCK does obviously makes the MACCK the superior system in this category. The TCO Armor does not dynamically monitor all networks of which it is a part to create a listing of active users, nor does it provide the ability to furnish acknowledgment of the receipt of messages. Further, the TCO Armor will give the user a message relating the amount of disk capacity that is left rather than the number of unread messages which are in the queue. These deficiencies give the MACCK the edge in communication management.

3. Command and Control

An exception to discussing only those requirements where one system shows a distinct advantage is made for this category. Although the TCO Armor possesses certain features which are superior in this category, the functionality at the individual platform level is greater with the MACCK. The TCO Armor provides excellent data correlation and filtration capabilities, as well as the ability to easily disseminate messages and graphics with the use of convenient autoforward tables. However, these capabilities are most useful at echelons above the platform and platoon level.

The MACCK gives the user a very reliable far target designation capability by utilizing the weapon platform's onboard laser rangefinder to interface with the command and control electronics unit. The MACCK allows for a more efficient total weapon system by reducing the number of working parts the crew must deal with to obtain a given result. This makes for a better system when analyzed from a human factors viewpoint.

Because both systems possess features superior to the

other in this category, they are given an equal ranking.

4. "User Friendly" Software

Software for the TCO Armor will be derived from the existing TCO software. This software is designed to provide capabilities needed at echelons far above battalion. The MACCK's software, on the other hand, was created specifically for users at the battalion and below level. This provides MACCK users a more tailored software package than will exist for the TCO Armor.

5. Reduce Electronic Counter-Measure Susceptibility

While the TCO Armor is neither radiation hardened nor provided a significant degree of emissions shielding, the MACCK, as a militarized system, is protected against electronic counter-measures to a degree equal to other components in the M1A1 tank.

6. Interoperability Priority

This category, in the near term, is perhaps the most important to decision makers who must choose between available communication systems. The advantage is given to the TCO Armor because it is a system designed for the Marine Corps and derived from a system that is in very strong contention for procurement by the Marine Corps. The MACCK has been designed for the Army to be compatible with existing Army communication systems. At this time, these systems are not fully compatible with Marine Corps systems.

7. Remote Display

The TCO Armor proves superior in this category because its design calls for a detachable display panel which could be moved throughout the weapon platform. This is not the case for the MACCK, which uses a fixed tactical display unit.

8. Cost

While not in the requirements matrix, cost is a primary consideration when making a systems comparison. Life Cycle Cost, focusing only on major cost differences between the

systems, was used as the measurement for the cost of each system. As presented in Chapter 6, the life cycle cost estimate for the TCO Armor was $9,877,646, while the life cycle cost estimate for the MACCK was $11,239,658. The two estimates produce a difference of $1,362,012. This amount, although significant, reflects a relatively small difference in the total cost of the systems over their service life. Because these cost estimates focus only on major cost differences between the systems, their amounts fall well short of the actual life cycle costs that would be incurred by the systems.

B. SYSTEMS COMPARISON AND RECOMMENDATION

Given the similar costs of the two systems, and the fact that neither meets all of the requirements set forth in Chapter 4, the degree of functionality provided by each system and key external factors must be considered in making a choice between the alternatives.

The overall functionality advantage goes to the MACCK. In dominating more of the requirements than the TCO Armor, the MACCK is the rational choice as the superior system. Making it even more appealing is the fact that it, unlike the TCO Armor, is designed to militarized standards and is based on equipment fully tested in a simulated combat environment. One of the TCO Armor's most significant shortcomings is its lack of solid testing in a field environment. The estimates of reliability factors are for the most part based on components tested in a static environment. The risk associated with the procurement of the TCO Armor will remain high until it has been fully tested in a rigorous combat-like environment.

However, in the near term, the risks involved with pursuing the TCO Armor concept are overshadowed by the MACCK's inability to interface with Marine Corps command, control, and communication systems. The superior functionality of the

MACCK is wasted on a weapon platform that cannot interface with its higher echelon. Instead of creating synchronization and unity of effort, the MACCK will serve to isolate the Marine Corps vehicle on which it is a part. Until the Department of Defense forces the services to adopt common standards and protocols so that the flow of information on the battlefield can proceed in a seamless manner, intra-service compatibility requirements will dominate functionality questions.

Therefore, the conclusion of this study is that unless the MACCK can be made to be compatible with existing Marine Corps command, control, and communication systems, the TCO Armor should be the system more vigorously pursued for procurement.

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